Typology Approach for
Building Stock Energy Assessment

National Scientific Report

CZECH REPUBLIC

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List of Abbreviations

SFH	Single family house
TH	Terraced house
MFH	Multi-family house
AB	Apartment block
RC	Reinforced concrete
th.	Thickness
H	Heating system
HG	Heat generator
HS	Heat storage system
HD	Heat distribution system
HA	Heat auxiliary energy
DHW	Domestic hot water system
WG	Hot water generator
WS	Hot water storage system
WD	Hot water distribution system
WA	Hot water auxiliary energy
SUH	Single-unit housing
MUH	Multi-unit housing

Introduction

The TABULA[1] project focuses on the development of a harmonized building classification structure for the European countries, with the purpose of performing energy assessment of the housing building stock. This classification of buildings, construction elements and supply systems is called a "typology", as it categorizes them into representative types or classes.

The purpose of this report is to describe the development of the Czech housing typology within the TABULA project. The research efforts undertaken to build the typology are described in the following chapters.

Chapter 1 – The TABULA approach to housing typology: Describes the objectives of the TABULA project and the general strategy followed to develop the Czech housing typology.

Chapter 2 – The Czech housing stock: Describes the research and data collection efforts to fulfil the following tasks:

- Acquisition of building data
- Acquisition of supply systems data
- Acquisition of data on the frequency of buildings and system types

Chapter 3 – Czech building typology: Describes the resulting Czech housing typology, based on the harmonized European structure developed within the TABULA project. The overall typology includes the classification of housing buildings, construction elements, supply systems elements and energy saving refurbishment measures.

Chapter 4 – Energy balance: Describes the Energy balance calculations according to the Czech methodology, and estimates energy savings by refurbishment in two categories: typical and advanced.

Finally, the main results of the research efforts here described are summarized into two specific deliverables within the TABULA project:

- The "Czech national building typology" brochure, which is a compilation of the Czech housing typology. The brochure contains an overview of the energy performance of typical buildings and the possible energy saving by refurbishment measures. It is a digital and printed document targeted to the general public, but specially to house owners, therefore it was written in Czech and in an easy to understand language.
- The Czech section of the TABULA web tool, an interactive tool designed to give a detailed overview of the energy performance of typical buildings and the possible energy saving by refurbishment measures. This web tool is targeted for European energy experts and the general public.

[1] The acronym TABULA stands for **T**ypology **A**pproach for **Bu**i**l**ding Stock Energy **A**ssessment

Chapter 1 The TABULA approach to housing typology

One of the objectives of the TABULA project is the development of a harmonized building typology for the European countries, with the purpose of performing energy assessment of the housing stock. The structure of the harmonized typology has been agreed between the TABULA partners to address the need of making different national typology approaches comparable. This common structure provides a basis for the analysis of the energy saving potential of the European building stock.

1.1 The TABULA typology

The harmonized TABULA typology consists of a “building typology” or building matrix, which classifies typical residential buildings according to their construction period and their characteristics, and sub-typologies, which classify typical construction elements and supply system and their respective typical refurbishment measures.

1.1.1 Building typology

Buildings can be classified into categories according to their typical physical characteristics (region, type and size) and construction period. This information together with statistical data of the frequency of each building type was gathered; relevant categories were identified and populated the main building typology. Each building type was described with the corresponding typical characteristics of the building envelope.

Further detailed information of the Czech building typology is presented in Chapter 2.

1.1.2 Building construction elements sub-typology

Additional information was needed to describe each building type. With this objective data about typical construction elements needs were collected.
Data about construction elements include typical wall, roof, floor, ceiling, windows and doors historically used for each building period, together with information about their energy performance. These sub-typologies are complemented with data about typical refurbishment measures in two classes: “typical” and “advanced”.

Further detailed information of the Czech building construction sub-typologies is presented in Chapter 3.

1.1.3 Supply systems sub-typologies

Similarly, data about supply systems and their typical components and energy performances were collected.

Data about supply systems elements include two main systems: space heating and domestic hot water. These sub-typologies are also complemented with data about typical refurbishment measures in two classes: "typical" and "advanced".

Further detailed information of the Czech supply systems sub-typologies is presented in Chapter 3

1.1.4 Overview of the TABULA typology

An overview of the TABULA typology approach can be seen in Figure 1 that shows the relationships between the building envelope and the supply systems that can be applied to each element of the building matrix.

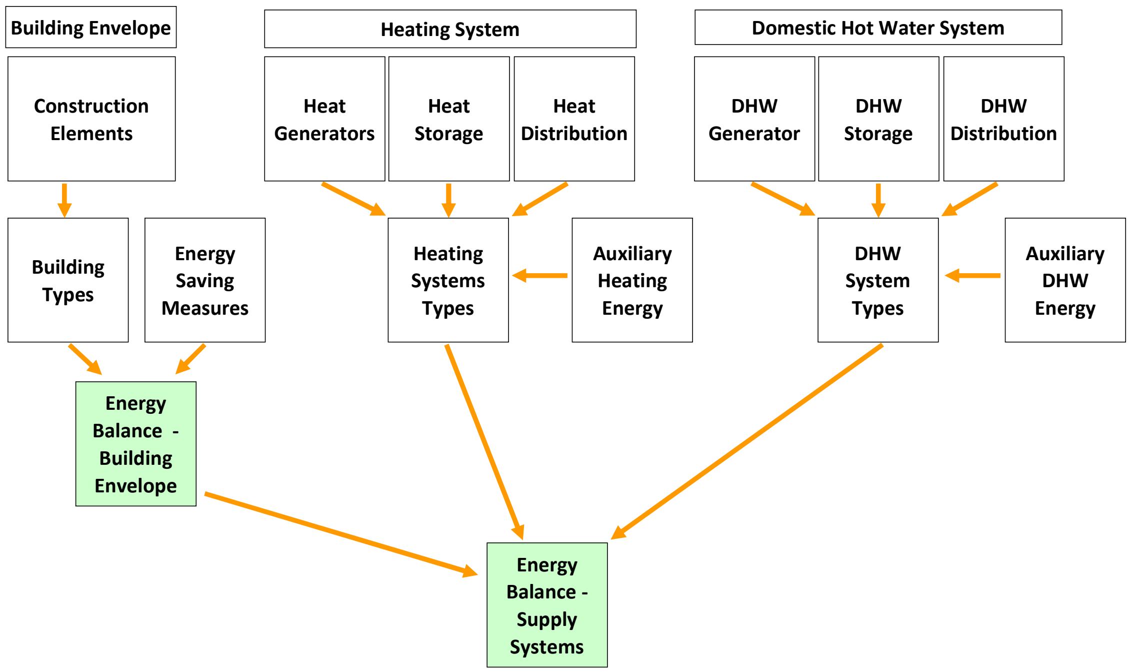

Figure 1 Overview of the TABULA typology structure

1.2 The Czech approach to the TABULA typology

Each of the partners of the TABULA project undertook different approaches to build their own national typology. In the case of the Czech Republic a national building typology does not officially exist, therefore STÚ-K developed the Czech typology following the strategy described below.

1.2.1 Data Collection

The Czech project is based on the technical documentation that is available in the archives of STÚ-K and STÚ-E, as these companies are successors of the state company STÚ s.p. that was a specialist for the development of standardized precast concrete systems and solutions for residential and public buildings.

Further sources of data included public databases of the Czech Statistical Office and other reliable sources of national statistical data, comprehensive technical guides for maintenance and refurbishment of large panel residential buildings and other standardized buildings, together with the experience of STÚ-K engineers who are in charge of technical assessment missions prior to the refurbishment of buildings and collect technical data about these buildings.

The data for the rest of the housing stock has never been systematically collected but some typological models were also created based on the knowledge of the old standards and building regulations. The frequency of various typologies could be partly calculated, given that some data is available in the archive copies of technical journal "Pozemní stavby" (1950-1990).

The energy performance data of around 60 basic types of large panel buildings are quite well known, as well as the strategic actions in order to reduce the energy consumption and CO_2 emissions. This segment of the Czech housing stock is highly important because one third of the Czech population lives in large panel buildings. Therefore this part of housing stock was thoroughly analyzed for data to be structured and made available.

The acquired data was completed through questionnaires addressed to energy specialists who regularly issue energy certificates for various types of buildings.

1.2.2 Data Aggregation

Data collected was organized and summarized with the purpose of creating a unique building typology or matrix that would represent the Czech building stock. This data aggregation resulted in the definition of specific building construction periods and building size categories presented in Chapter 3.

Similarly, a historical inventory of construction elements and supply systems and their energy performance together with their typical refurbishment measures resulted in representative sub-typologies that are also presented in Chapter 3.

1.2.3 Data Analysis

Scenarios were developed to study the energy performance of each building type in three different situations: current state, after a typical refurbishment, and after advanced refurbishment. These scenarios were designed combining each building type with typical building and system components, and were analyzed using the TABULA.xls spreadsheet elaborated within the TABULA project. This analysis resulted in estimations of energy performance and potential energy saving measures for each case.

These scenarios were analyzed and compared with other similar information available. An informative brochure for each building type was created to summarize the results for the general public.

1.2.4 Comparison of TABULA approach with national EPC methodology

The TABULA standard reference calculation is based on the respective CEN standards:

- calculation of the energy need for heating: EN ISO 13790 / seasonal method
- calculation of the delivered energy: EN ISO 15316 / level B (tabled values)

The energy demand is determined by use of a simple energy performance calculation procedure based on the above mentionned CEN standards.

<u>Energy need for heating</u>
Standard Reference Calculation - based on: EN ISO 13790 / seasonal method
The energy need for heating was calculated by applying standard boundary conditions and relevant national climate data.

The energy balance TABULA method has the following boundary conditions:
Room temperature: 20°C
heating base temperature: 12°C
Climatic data: heating period corresponding to heating base temperature definition, mean value of exterior temperature in the heating period
cumulative values of the solar radiation in the heating period
standard values for the night setback depending on the building type (0,8 to 0,9 for SFH and 0,85 to 0,95 for MFH)
hygiene conditions of use : air exchange in the room 0,4 h^{-1}; interior heat gains 3 W/m²; shading factor 0,6
DHW use: 10 kWh/(m²a) for SFH and 15 kWh/(m²a) for MFH
Above mentionned values are related to TABULA reference floor area

<u>Energy performance of the supply systems</u>
Standard Reference Calculation - based on: EN ISO 15316 / level B (tabled values)
Basis for this calculation were tabular values for heat generation, storage, distribution and auxiliary energy - each for space heating and domestic hot water. The respective

values for these system components were determined at the national level according to the standard ČSN EN 15316 (national version of EN ISO 15316) and entered into the TABULA database.

The Czech national EPC method is based on calculation of total annual energy consumption, including heating, cooling, ventilation, auxiliary and other energy required for building operation (calculation of delivered energy for standardised building operation).

Simplified multizone model has been introduced for this purpose. The building is divided into several zones with specific boundary conditions. The zone operation profiles include occupation, lighting, indoor environment requirements and auxiliary energy.

Building energy systems including heating, cooling, hot water generation and ventilation are incorporated as zone assigned systems, while energy sources (e.g. boilers, co-generation unit, solar collectors etc) are in the model assigned to the energy delivery systems. Result of energy performance calculation for assessed building is benchmarked with existing average level of similar buildings and required level to obtain energy performance certificate according to EPBD. Four climate regions with synthetic data are used as defined by the Czech standard CSN 730540, supplement H1.

Typical boundary conditions in apartment building are:

room temperature	20°C
staircase temperature	16°C
basement temperature	10°C
air exchange in living spaces	0,3-0,5 $^{-1}$
air exchange in other spaces	0,1 h^{-1}
heat gains from persons	3 W/m^2
heat gains from equipment and appliances	3 W/m^2
lighting in living spaces	4,46 $kWh/m^2.a$
lighting in other spaces	1,10 $kWh/m^2.a$

The cold bridges can be either calculated or defined as U value increment in the range between 0,02 W/m^2K (optimized with 3D calculation) and 0,20 W/m^2K (neglected building).

DHW use calculation examples:

Appartment 75 m^2:	28 m^3 / year (or 588 kWh/year/person+losses)
SFH 150 m2:	53 m^3/ year (or 695 kWh/year/person+losses)

Primary energy and CO_2 emissions are not assessed in the Czech energy performance certification.

Chapter 2 The Czech housing stock

This chapter summarizes the findings of the research on the Czech housing stock, its compositions and characteristics. Information found was the base to create the Czech building typology described in Chapter 3.

2.1 Data Sources

The statistical data of buildings were mainly obtained from the public database of the Czech Statistical Office (CZSO). Most of the figures are originating from the national census that was held in 2001. Additionally some data is available from the microcensus ENERGO 2004, these data are related mainly to the energy consumption in the households (types of fuel, frequency of system types and their age structure, energy consumption).

2.1.1 Public Database (VDB)

The Public Database (VDB) is developed as a fundamental and unified data source for presentation of statistical data designed mainly for the public. It contains solely aggregated statistical data covering all observed areas of statistics. It uses results of statistical data processing in the CZSO as well as statistical data from external and administrative sources especially from other work places of the state statistical service. It does not focus only on data covering the Czech Republic; additionally it provides data for territorial administrative units of the Czech Republic (regions, districts, municipalities and cities, etc.) and also data from abroad.

VDB is created as a data mart drawing data from databases developed in the process of statistical data processing. Some data are presented in a different context in different outputs (tables, maps, graphs, etc.).

VDB includes the following:

- Primary level – containing mainly database of aggregated statistical data.
- Secondary level – containing statistical outputs (statistical tables, maps, graphs).
- Interface – applications securing transformation and input of data to primary database (including universal XML interface) and applications enabling access to data and outputs.

2.1.2 ENERGO 2004

The microcensus ENERGO 2004 [6]covered approximately 1 % of total 3.700 000 occupied dwellings. Thus the statistical population was approx. 40 000 dwellings. The structure was defined adequately to the structure of the housing stock resulting from the census 2001.

2.2 Data Inventory

2.2.1 General Information

The inventory was carried out by searching for multiple sets of relevant data. This activity has brought a clear picture of data availability on the frequencies and technical parameters of the housing stock and on the climatic conditions. The legal framework for EPBD implementation and present calculation methodology used for energy performance certificates were also within the scope of inventory. The inventory task helped to identify the gaps in the information resources. The most serious data gaps were found in the typologies of single family houses and terrace houses.
The degree and quality of refurbishments for these categories is unknown and can be only very roughly estimated. The same applies to the systems as regards their age structure and efficiency.

2.2.2 Climate and regions

According the Czech standard ČSN 730540, Annex H1 [8] the Czech Republic is divided into four climatic regions with reference to the data of CHMU (Czech Hydro Meteorological Institute). The Czech national calculation methodology supported by NCT (Czech National Calculation Tool) has adopted twelve synthetic reference days in hourly time-step temperature values for every climate region. Source data are in hourly temperature values format during the year (8760 values in total). Climate data for methodology are processed in typical day format where every month represents just one typical day. Typical day for winter temperature is average of all separated values in month and in given time-step interval.

The national calculation methodology is operating with average solar radiation values which were calculated for every day of particular month in the year. The sunshine duration data are resulting from long-term (30 years) observations of Czech Hydro Meteorological Institute. The measured values were recorded through heliograph (records of sunshine duration during month).

The Czech TABULA approach is simplified. Only one synthetic climate region is used for the whole territory of Czech Republic. This decision is partly based on consideration of accuracy of other data sets and can be also justified by the average air temperatures map in Figure 2 and by the figures from Table 1.

Table 1 Description of climatic regions in the Czech Republic

Region	Main cities	Heating season		Average global irradiation				
		HDD per year	Ext. air temperature Avg. [°C]	Horizont. [kWh/a]	East [kWh/a]	South [kWh/a]	West [kWh/a]	North [kWh/a]
National	Czech Republic	217	3.8	374	225	396	225	99
North West	Liberec, Usti Nad Labem, Karlovy Vary	221	4.0	385	231	407	234	104
South West.	Prague, Plzen, Č.Budejovice	215	3.8	369	223	382	220	96
North Center	Hradec Kralove, Pardubice	217	3.8	372	226	399	227	100
South Center	Jihlava	226	3.4	416	249	398	248	111
North East	Olomouc, Ostrava	212	3.5	355	212	390	213	94
South East	Brno, Zlin	208	3.6	354	211	385	212	94

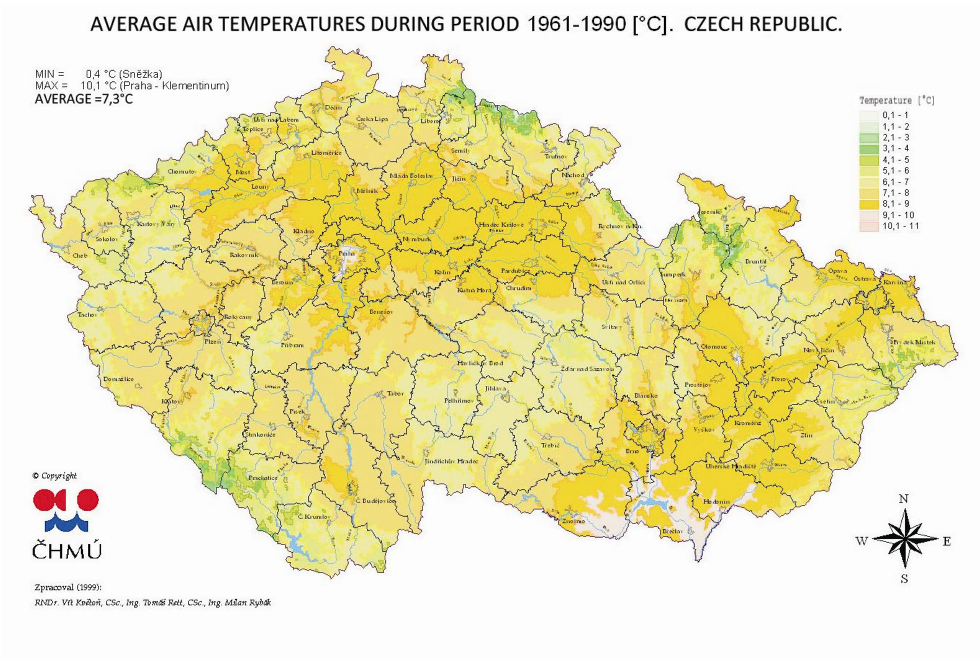

Figure 2 Average Air Temperatures in Czech Republic

2.2.3 National housing stock

The data for frequencies of dwellings and average floor areas are originating mainly from statistical data collection during national census 2001. The values are show in Table 2 and Table 3.

Table 2 Frequencies of buildings according to number of dwellings and storeys [1]

SFH total	Number of dwellings		APT total	Number of dwellings		
	1 dwell.	2-3 dwell.		2-3 dwell.	4-11 dwell.	12 dwell.and more
1 406 806	1 155 379	251 427	195 270	13 206	106 538	75 312
SFH total	**Number of storeys in SFH**		**APT total**	**Number of storeys in APT**		
	1-2 storeys	**3-4 storeys**		**1-2 storeys**	**3-4 storeys**	**5 storeys and more**
1 406 806	1 369 230	25 485	195 270	37 550	92 183	65 207

Table 3 Average floor areas according to construction period and type of building

Building type	Average gross floor area (m^2)		Average living area (m^2)	
	per dwelling	per occupant	per dwelling	per occupant
1961				
SFH			35,29	10,29
APT			34,94	10,81
1970				
SFH	68,33	20,99	41,94	12,88
APT	55,67	18,34	35,68	11,75
1980				
SFH	77,25	25,82	49,44	16,53
APT	57,38	20,02	36,86	12,86
1991				
SFH	85,78	29,4	56,77	19,46
APT	59,77	22,51	38,16	14,37
2001				
SFH	96,67	33,63	63,03	21,93
APT	61,08	24,67	39,42	15,92

Table 4 Frequency of building types of the national building stock [1]

Building period	Total number of buildings	
	Single family houses and terrace houses (1000)	Apartment blocks and multifamily houses (1000)
until 1919	226,50	25,85
1920-1945	290,00	26,70
1946-1980	527,75	103,30
1981-1990	189,50	25,70
1991-2001	155,00	11,50
Total	**1 388,75**	**193,00**

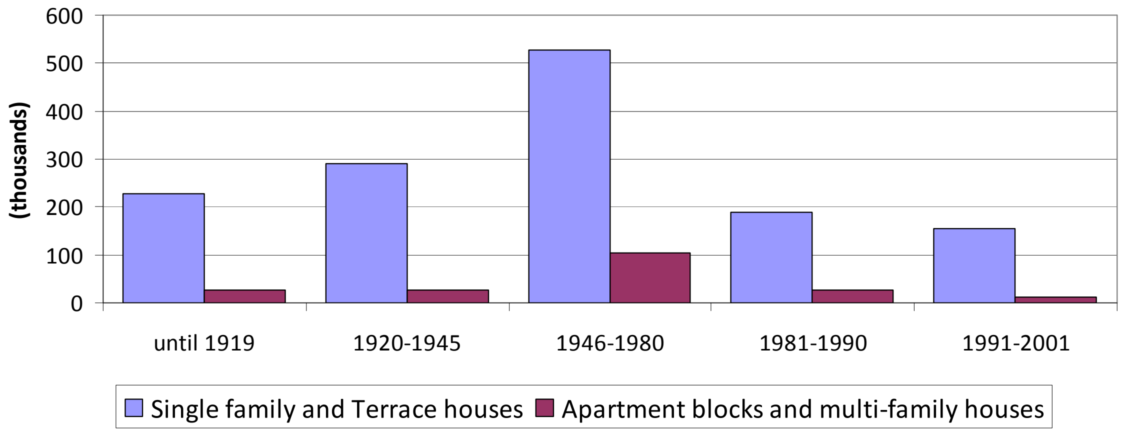

Figure 3 Frequency of building types of the national building stock

2.2.4 Characteristics of the housing stock

The information about the level of refurbishments of the housing stock can be found in Table 7 and Table 8.

Table 5 Heated area of the national building stock by building period [1]

Building period	Heated area [m²].	
	Single family houses and terrace houses (1 000 m^2)	**Apartment blocks and multifamily houses (1000 m^2)**
until 1919	17 365,60	8 543,45
1920-1945	23 163,70	12 099,40
1946-1980	48 639,90	70 648,20
1981-1990	18 615,90	24 370,90
1991-2001	16 695,20	8 217,95
Total	**124 480,30**	**123 879,90**

Table 6 Historical overview of U-value requirements for external walls [8] .

<table>
<tr><th>Period</th><th>External walls
U-Value [W/m²K]</th><th>Standard</th><th>Comments</th></tr>
<tr><td>Before 1963</td><td>1,396</td><td>ČSN1450, ČSN 730020</td><td></td></tr>
<tr><td>1963 – 1978</td><td>1,38 – 1,47</td><td>ČSN730540 new</td><td>Climate zones, interior comfort based</td></tr>
<tr><td>1979 – 1992</td><td>0,79 – 0,89</td><td>ČSN730540 revised</td><td>Climate zones, interior comfort based</td></tr>
<tr><td>1992 – 1994</td><td>0,46 – 0,73</td><td>ČSN730540 rev. 4</td><td>New/renovations energy demand based</td></tr>
<tr><td rowspan="3">From 1994</td><td>0,35 – 0,50</td><td rowspan="2">ČSN730540-2</td><td>Heavy walls recom./min.</td></tr>
<tr><td>0,31 – 0,44</td><td>Light walls recom./min</td></tr>
<tr><td></td><td></td><td>Climate zones, interior comfort based</td></tr>
</table>

Table 7 Percentage of thermally refurbished envelope areas [3]

<table>
<tr><th rowspan="2"></th><th colspan="2">Large panel buildings
(precast concrete)</th><th colspan="2">Masonry buildings</th></tr>
<tr><th>SFH+TH</th><th>MFH+AB</th><th>SFH+TH</th><th>MFH+AB</th></tr>
<tr><td>Number of dwellings (1000)</td><td>neglected</td><td>1199,20</td><td>1632,1</td><td>961,60</td></tr>
<tr><td>Heated area related (1000 m²)</td><td>neglected</td><td>72048</td><td>157824</td><td>57773</td></tr>
<tr><td>Windows replacement or renovation</td><td>unknown</td><td>34 %</td><td>unknown</td><td rowspan="3">12%</td></tr>
<tr><td>External thermal insulation of the facade</td><td>unknown</td><td>32 %</td><td>unknown</td></tr>
<tr><td>Roof renovation</td><td>unknown</td><td>28 %</td><td>unknown</td></tr>
</table>

Table 8 Average insulation thicknesses (eq EPS 70F) added to the refurbished elements and U values of new windows [9]

	1998	2008	2012 *(estimation)*	Remarks
Walls	50-60 mm	85 mm	100 mm	[a]
Windows U values (W/m^2.K)	2,3-2,8	1,4-1,8	0,8-1,2	[b]
Roofs / upper floor ceilings	120 mm	160 mm	220 mm	[b]
Basement / cellar ceiling	50 mm	75 mm	100 mm	[b]

[a] Source: Sdružení EPS ČR Prague 2009

[b] Source: Mainly based on estimations and standard requirements

The data about heating and DHW systems was mainly collected during the microcensus ENERGO [6]. These values are presented in Tables 9 to 11.

Table 9 Centralization of the heat supply for space heating [6]

Number of dwellings	SPACE HEATING SYSTEMS							
	CENTRALIZED HEATING				LOCAL HEATING			
	A	B	C	D	E	F	G	H
Fuel	Total centralized heating	Central heating (building or apt.)	Collective heating	District heating	Complement Heating	Kitchen stoves	Stoves	Open Fires
Total number	**3 489 122**	**1 931 195**	**386 680**	**1 171 248**	**32 522**	**73 220**	**812 772**	**61 461**
Electricity	0	0			28 480		364 723	
Natural Gas	1 116 126	1 116 126			3 307		239 137	
LPG	3 859	3 859			0		2 848	
Heat	1 557 928	0	386 680	1 171 248	0	0	0	
Hard Coal	46 119	46 119			0	3 583	9 371	
Coke	37 299	37 299			0	184	2 205	
Wood	367 938	367 938			735	69 362	115 940	61 461
Other Fuels	359 854	359 854			0	92	78 549	

Table 10 Heat supply in the households (% of dwellings) [10]

Year	District heating [%]	Other					
		Solid fuel [%]	Fuel oil [%]	Gas [%]	Propan-butane [%]	Electricity [%]	Other [%]
1991	36,95	43,78		16,57	0	1,5	1,2
2009	36,84	17,62	0,09	39	0,2	6,25	0

2.2.5 Energy/Fuel consumption by households

Table 11 Energy consumption in statistical population of 40 000 dwellings [6]

Building categ.	Energy Carrier								
	Electricity	Gas	LPG	Brown coal	Coke	Wood	Other	DH	DHW
	MWh	MWh	kg	tons	tons	kg	tons	TJ	$10^3 . m^3$
SFH (1 dwell.)	55919,9	160615,3	132318,0	14900,9	816,0	19874424,0	1976,6	3,6	1,4
SFH (2-3 dwell.)	26520,7	89553,7	51729,0	6058,9	557,4	7955942,0	947,7	3,1	1,7
MFH	18268,7	49191,2	21465,0	1616,8	95,6	1763855,0	187,5	78,6	57,8
AB	33391,3	36002,3	6015,0	166,1	5,4	182209,0	36,9	465,6	448,2
Total	**134100,5**	**335362,5**	**211527,0**	**22742,7**	**1474,4**	**29776430,0**	**3148,7**	**551,0**	**509,1**

Table 12 Fuel consumption for the heat generation and delivery to the households (heating+DHW) [6]

District heating	Collective heating	Electricity	Natural gas	
		Boiler or instant heater	Boiler DHW	Boiler DHW+heating
31,90%	10,90%	34,80%	12,60%	13,60%

Table 13 Fuel consumption for the heat generation and delivery to the households (heating+DHW) [7]

Fuel	Decentralized heating (TJ)	District heating (TJ)	Total (TJ)
Brown coal	-	20 056,6	39 607,3
Brown coal graded	17 307,3		
Briquettes	2 229,3		
MULTI powder	-		
Lignite	-		
Lignite graded	14,1		
Black coal	-	5 068,2	8 106,1
Black coal graded	2 486,3		
Black coal sediments and granulate	37,5		
Coke	514,1		
Wood	29 481,0	720,6	30202
Wood chips, wood waste			
Wood pellets and briquettes			
Vegetal materials non agglomerated	-		
Cellulose extracts	-		
Other biomass	-		
MSW	-	1523,4	1523,4
Industrial and hospital waste	-		
Alternative and other fuels	-		
Carbon deposits	-	-	-
Fuel oil	-	1 535,8	1 535,8
Tar mixture	-	296,0	1 124,9
Organic chemicals	-		
LPG	828,9		
Other liquid fuels	-		
Natural gas	88522,1	17 278,8	105 800,9
LFG	-	-	-
Other biological gas	-	-	-
Degazation gas		840,2	840,2
Gasworks *gas*			
Coke oven gas			
Blast furnace gas			
Oxygen steel furnace gas			
Other types of gas			
Electricity	25191,6	3,7	25 195,3
Waste heat, recovered heat	-	-	812,3
Nuclear fuel	-		
Solar collectors	118		
Heat pumps	694,3		
TOTAL (TJ)	**167 424,9**	**47 323,4**	**214 748,2**

Chapter 3 Czech building typology

3.1 Building Type Matrix

The Czech building typology within the TABULA project consists of 24 building types divided into 6 construction periods and 4 building size categories.

3.1.1 Construction periods

3.1.1.1 Before 1920

The most common structural building system was solid masonry, but already by the end of 19th century there was a trend to separate the load-bearing and thermal insulating functions, initially by building masonry pillars with big load bearing capacity and window sills with good insulating properties.

The walls of the oldest houses are a mix of brick masonry and natural stone. Later, the stone was used only as a secondary material - usually for the basement - the wall structures in the upper floors of buildings were made of solid or hollow brick, hollow brick blocks, blocks of light concrete (mostly concrete with granular slag or pumice) and blocks of so called Calofrig (diatomite).
They were used as the adobe (unburned bricks from clay mixed with mulch, straw, hay or sedge), especially in rural and low-rise buildings, buildings bearing thick brick walls were variable according to the number of floors of the building. The minimum thickness of the wall on the top floor due to freezing was 450 mm and downward.

Roofs were built mainly with wood trusses pitched with clay tiles, covering of straw or wood shingles, which have already largely disappeared. Roof metal (copper and lead) were used very rarely because they were too much expensive. The attic was mostly uninhabited (unheated attic). The basement cellars were built with arched brick vaults.

Floors at ground level in buildings with no basement were carried out either with compacted clay, paving stone or ceramic tiles or timber joists with boards on damp proof course to prevent the wood from moisture build up. In most cases, the original subfloor has been replaced with concrete screed with different compositions and successive layers. It was popular to use the linoleum or later also PVC flooring. Floors show totally inadequate U-values.

Plastered ceilings with reed reinforcement were frequently used.

The windows were wooden with parallel glazing; outer wing was originally opened out. The buildings prior to the renovation show large heat losses with a number of cold bridges and substantial damages caused by humidity.

Table 14 Summary of Construction Elements for the period before 1920

Element	Description	U-Value [W/m²K]
Roofs	roofing tiles , battens, rafters, not insulated	2.60
Ceilings	traditional timber joist ceiling with (open-nail) flooring, dead floor - laggings - (peeled, trimmed slabs; joints filled with clay), slag (sound and heat insulation) and ceiling plaster	1.20
Floors	floor natural stone or tiles or lime clay screed with no insulation	3.23
	steel beams, brickwork vault, wooden flooring	0.80
Walls	masonry solid bricks 600 mm	1.10
	masonry solid bricks 450 mm	1.36
	masonry solid bricks 300 mm	1.80
Windows	secondary glazing 2 frames, distance between frames 150-200 mm	2.40
Doors	wooden door with no glazing	3.50

3.1.1.2 1921 – 1945

After 1918 there was a massive construction development in the newly formed Czechoslovakia. The development stimulated not only new possibilities of financing construction, but also simplifying the building regulations. The minimum thickness of brick masonry construction was 450 mm, however few exceptions from the regulations could be used by builders that is why uninsulated gable masonry walls only 300 mm thick can be still found in many buildings. Most exceptions were used in the construction of cheap housing, which was considerable interest, especially in the late twenties and mid thirties.

From this period come around 745,000 dwellings, of which about 486,000 dwellings in family houses and nearly 260,000 in residential buildings. They were built mainly of brick masonry buildings, but also the construction of the normal frame structure with brickwork.

Construction technology compared to the previous period didn't change much, however extensive applications of reinforced concrete structures can be observed.

Typical roof constructions were timber roof trusses with clay tile roofing. The attic was mostly uninhabited (unheated attic). Flat roof terraces regularly appeared in functionalist and modern architecture. Basements with brick vaults or concrete vaults, often set in a steel beam, or more progressive cast in situ reinforced concrete slabs, or cast in situ reinforced concrete continuous beam floor structural systems (called Hennebique) were used.

Floors at ground level in buildings with no basement were carried out either with compacted clay, paving stone or ceramic tiles or timber joists with boards on damp proof course to prevent the wood from moisture build-up. Floors show totally inadequate heat transfer coefficients U.

Plastered ceilings with reed reinforcement were still used quite often. Cast in situ reinforced concrete floor slabs or floor structures using extruded structural clay units (hourdis) were also frequently used.

The windows were wooden with parallel glazing; outer wings have usually opened inwards.

Substantial cold bridges in areas such as window lintel beams or balcony cantilevers. Houses, unless they have been restored are often damaged by capillary moisture and condensing moisture in areas with cold bridges that support biological contamination It has been observed over the past few years that moisture problems have dramatically increased after the replacement of original windows with the new ones due to lack of ventilation bad ventilation control.

Table 15 Summary of Construction Elements for the period between 1921 – 1945

Elements	Description	U-Value [W/m²K]
Roofs	roofing tiles, battens rafters +cork or heraklit	1.64
Ceilings	reinforced concrete, 10 mm insulation, cement screed	2.20
Floors	reinforced concrete, 10 mm insulation, cement screed	1.50
Walls	masonry solid bricks 600 mm	1.10
	masonry solid bricks 450 mm	1.36
	masonry solid bricks 300 mm	1.80
Windows	secondary glazing 2 frames, distance between frames 150-200 mm	2.40
Doors	wooden door with single glazing	4.70

3.1.1.3 1946 – 1960

As previously mentioned, the basic and the only criterion for evaluating and assessing the thermal insulating properties of external masonry was 450 mm thick solid brickwork. This criterion was first mentioned in the standard for calculating heat losses from 1949 and was maintained even after the revision of this standard in 1955. These standards have already stipulated the heat performance requirements in the form of heat transfer coefficient k.

In the post-war years there was a massive development in public housing constructions. At the first stage, the standards followed the housing regulations from the pre war period.

The nationwide two-year plan with housing development plan was announced at the end of 1946. Buildings originating from this period have exterior masonry walls built with bricks and cinder elements. Efforts to industrialize the construction process after 1948 led initially to standardization of building elements and later to standardization of whole building types. The standardized building types were "T" (T 01, T 02, T 03, T 11, T 12, T13). The traditional solid bricks were partly replaced with large masonry blocs and wall block elements. Some of these wall elements were produced to comply with one storey height, but their length was limited.

The most common standard thickness of solid brick exterior walls was 450 mm. For buildings with more storeys (5 to 6 floors) the wall thickness 600 mm was used on the first and second floor level. Some gable walls still had only 300 mm. In case of hollow bricks or cinder blocks, the wall thickness was 375 mm, but the gable wall thickness appeared smaller again - 250 or 300 mm. The window sills were sometimes thin - either due to embedding of heating radiators or striving to fill rapidly space between the load bearing window pillars made of masonry blocks.

The sill thickness was 300 mm or 350 mm when using solid bricks and 250 mm when using honeycomb bricks (CDM). Parapet walls were lined in some cases as a cavity (2 x 150 mm solid brick masonry and 50 mm air gap), sometimes insulation board from the inner side was applied using materials that could receive plastering.

Early examples of precast solutions - partly precast light window elements that were used for the building type T 16. Precast reinforced concrete frame filled with 100 mm insulation board (Welit) covered from both sides by thin steel wire fabric Rabitz thus preparing surface ready to apply plaster.

In this period the load bearing capacity of external wall was the decisive parameter to define the wall thickness. It was not the heat-insulating ability. During the operation years of above described buildings especially gable walls were showing lack of insulating properties. Many of gable walls were additionally insulated by using either Heraklith (magnesite-bound lightweight wood wool board) or more efficient Lignopor (combined board polystyrene+Heraklith). Heraklith was used in thicknesses from 35 to 50 mm; Lignopor was used in thicknesses 25 and 35 mm.

Roofs of the "T" building types were largely inclined with wooden rafters, in later periods with beams having some elements of prefabricated reinforced concrete. The attic floor and cellars were in most cases unheated and unused. From about mid-fifties flat roofs were used on a larger scale,

Thermal insulation of roofs was most frequently performed of light cast concrete in a variable thickness that was simultaneously used to build a slope. Minimum thickness of 40 mm was prescribed for this type of layer. . As a base layer for the waterproofing felt a cement screed about 30 mm thick was usually used. The layers of lightweight concrete were separated with dilation joints in about 5 m distance. Another option was to perform thermal insulation of insulating boards (eg Olcelyt, Empa boards, glass or slag wool thickness of 30 mm or bitumen cork boards of thickness 35 mm) that were laid on a supporting structure in a sand or asphalt layer and covered with an ordinary bitumen cardboard. Subsequently a roofing slope was created either with light aggregate or with light concrete.

Initially mostly timber floor structures built with joists were used, later constructions switched to prefabricated solutions, which were classified by weight. Floor structures assembled from components weighing up to 300 kg, I beams used in combination with granular slag concrete or ceramic inserts. They were used primarily for the types of T 12, T 13, T 14, T 15 and T-20.

The floor structures consisting of reinforced concrete beams coupled with segmented reinforced concrete slabs were standardized for the same spans as previously described types. These structures were designed in areas where smooth soffit was not required, therefore, mostly in the basement ceiling.
The hollow core reinforced concrete floor slabs were standardized for the spans less than 3 m. These precast concrete elements were applied in building type T 22.
The most heavy floor structures (elements weighing up to 1500 kg) were again the hollow core slabs, but with larger dimensions. These elements were used in the building types T 16, T 12, T 13 and T15.

Floors under unheated attic were designed both trafficable and non-trafficable. The oldest types were handled similarly as trafficable floors in pre-war homes that means usually a slag layer as a base for a layer of concrete or granular slag concrete and the top layer of brick tile of thickness about 30 mm. Later it was dropped from use of tiles, a top layer of concrete or granular slag concrete with a layer of cement screed was most frequently applied. The total thickness of the floor ranged from 100 to 150 mm. The floors were mostly non-trafficable only "paths" to access the chimneys were built. The thickness of cinder or slag used for the purpose of thermal insulation was in the beginning about 100 mm after the modification of the Czech standard CSN 73 0540 the thickness of this insulating layer increased by about 50 mm.

The total thickness of the floors in the initial period was 150 mm, later it dropped gradually to 100 and 50 mm. Thermal insulation materials were developed such as Empa plates, Isoplat etc. and their functionality has been enhanced by layers of slag or layers of lightweight concrete (mostly granular slag concrete).

The joinery in residential buildings includes mostly windows, balcony doors and entrance doors. Wooden windows with parallel glazing predominate in buildings constructed in the period 1946 to 1948. Single glazing was used only in cellars, corridors and staircases. The natural light was often brought to staircases through glass blocks with concrete joints (Luxfer).

First prefabricated blocks of flats appeared around 1954. It was a building type "G". These objects represent the beginning of construction of large panel residential buildings in the former Czechoslovak Republic. The type "G" building with transversal load bearing walls was developed in Zlín in Moravia in 1953. It was the result of efforts to achieve a maximum degree of industrialization, rapid and relatively inexpensive way of construction of residential houses.
After a period of pilot projects and individual regional implementation of object-type G40 and its mutations, the national construction of large panel buildings type G57 began in 1957. This was fully implemented in 1960 with minimal modifications. External walls were single layer of light concrete (either granular slag or cinder pumice concrete), or sandwich elements with the use of internal insulation layer of “silicork” (similar to the current very lightweight aerated concrete) and concrete filled with organic particles. The largest share of housing construction in the former period had a G57 system construction in 1964, when it was built more than a third of all dwellings.

Table 16 Summary of Construction Elements for the period between 1946 – 1960

Elements	Description	U-Value [W/m²K]
Roofs	roofing tiles, battens rafters +lignopor or heraklit	1.25
	roofing tiles, battens rafters +glasswool thin insulation in the cavity	0.80
	warm flat roof	0.91
Ceilings	timber joist ceiling with thin insulation layer between joists	1.30
	cavity blocks ceiling below unheated attic spaces, 40 mm insulation	1.45
Floors	concrete floor slab above technical spaces with installations, hollow core slab, 25 mm insulation	1.10
	concrete floor on the soil 25 mm insulation	1.13
Walls	masonry 375 mm cavity brick CDk	1.43
Windows	double frame casement window with 2 panes, 50 mm distance between panes	2.90
Doors	wooden door with single glazing	4.70

3.1.1.4 1961 – 1980

The first technical standard purely focused on thermal behaviour of building materials and products was developed specifically for thermal-technical properties of building construction in 1962. The requirements were stipulated through the values of thermal resistance (R). The minimum value of thermal resistance is increased depending on the ability of accumulation of construction and heating system (intermittent or continuous). The standard is also referring to cold bridges, but only in the sense that they are unacceptable. The issue of air permeability, diffusion and condensation of structures is also addressed, but only verbal instructions and recommendations.

In 1964 the above mentioned technical standard was reviewed and some values were updated. The revision was done mainly due to more realistic values determining the thermal conductivity of lightweight concrete (concrete, slag pumice, expanded clay, expanded shale and slag) for designing the thickness of external wall units. The prefabricated houses originating from this period show many defects due to non-satisfactory heat protection (vapour condensation on the inner surface of structures, mould, fungi, etc.) Criterion values of thermal resistance in terms of transient and steady-state temperature remained - except for a few minor adjustments - the same as in the previous standard. The concept of equivalent thickness of the brickwork as a criterion for assessing the thermal insulation of walls has been removed from the standards. The standard also included a procedure for determining the width of the thermal bridge. The issue of air permeability of building structures has been commented upon in this case only verbally. The vapour diffusion and condensation issues were addressed. The vapour condensation was considered satisfactory provided the annual balance was active, i.e. the quantity of vapour condensed in the building element was lower than the amount that can evaporate.

Another version of CSN 73 0540 was published in 1979. The thermal resistance of structures was differentiated by both temperature regions, partly in the external structures, the values increased approximately twofold. The units were already in m^2KW^{-1} (or $Wm^{-2}K^{-1}$ for heat transfer coefficient). Some exceptions were adopted for buildings constructed in year 1983 (or until 1985) regarding the thermal resistance requirements. For the first time the requirements for windows and doors were stipulated and four categories of floors were introduced according to their heat accumulation capacity: very hot, hot, less hot and cold.

The construction of a block of flats type G57 in each region began to emerge further modifications of the national development type, which differed mainly in composition of external walls, roof solution, structural height and the use of elevator. The outer walls were opaque as single-layer and sandwich elements with layer of thermal insulation inside the panel. For single-layer walls mostly lightweight concrete elements were used with slag, pumice and expanded clay aggregates. Since 1965 typical sandwich elements with different thermal insulating materials such as urea resins, glass fibre and later expanded polystyrene - between two layers of reinforced concrete. Construction of houses was carried out with external opaque masonry walls of brick. In areas with a shortage of burnt clay products cinder or slag concrete elements were used. Implementation of a block of flats G series was a significant step towards the industrialization of the housing construction process. This objective was achieved mainly by focusing on factory production activities and reducing site works. This narrow focus however impacted the architectural and urban quality. Later on increasing demand for improvements and elimination of the causes of defects was observed. Great pressure to increase the construction of prefabricated houses was due to growing housing shortage. In 1959 the Czechoslovak government introduced a priority axis for new development of standardized solutions for residential buildings .The same year new trends in architecture and layout as well as new technology and design solutions were tested in experimental projects in several mutations including new types of cladding. . In 1960 a 1962, have implemented an experimental housing. Based on results of pilot projects from the years 1960_1962 two new structural systems (T 06 B and T 08 B) have been developed nationwide, and started to be used collectively since 1965. The above mentioned structural systems have become the most widely used large panel systems in the Czech Republic. During the processing of standard technical documentation, the philosophy had changed and the documentation switched from standardisation of the complete structural systems to standardisation of construction elements. As a result of this approach some construction elements like e.g. cladding systems were not a part of the new mandatory technical files and interchangeability was made possible. Due to this situation regional structural mutations were developed. In 1972 technical documents were approved for the new type of large panel systems (especially B 70, BANKS, HKS 70, PS 69, LARSEN-NIELSEN, VVÚ-ETA, NKS). Large number of sandwich wall elements was designed with a heat insulating material of expanded polystyrene with a thickness 40, 50 and 60 mm. Masonry construction was slowing down in this period. It was focused mainly on the gas aerated concrete blocks and masonry blocks. The lightweight concrete elements used in the individual housing projects were partly replaced with timber frame sandwich elements. In the late sixties the precast concrete technology greatly predominated over other construction. This situation remained practically unchanged until 1990.

Table 17 Summary of Construction Elements for the period between 1961 – 1980

Elements	Description	U-Value [W/m²K]
Roofs	lightweight concrete slab 150mm + screed 30mm	0.85
	warm flat roof	0.57
Ceilings	reinforced concrete, 40 mm insulation, cement screed	1.60
Floors	reinforced concrete slab above basement, th. 200 mm	1.28
Walls	flooring th. 3mm - cement screed th 40 mm - waterproofing A400 H - Fibrex th 20mm - Precast concrete floor th 190mm	1.24
	lightweight gas aerated masonry 300 mm	1.01
	precast lightweight pumice element	1.42
	precast wall element	1.20
	chipboard th 19mm - polystyrene th 25mm - air gap th 30mm not ventilated - glass th 3mm	1.10
	RC th 100mm - Poly EPS 40mm - RC th 50mm	0.99
	RC th 150mm - Poly EPS 40mm - RC th 50mm	1.25
	RC th 100mm - Poly EPS 60mm - RC th 60mm	0.93
	slag concrete, expanded clay concrete 300 mm	1.40
Windows	double frame casement window with 2 panes, 50 mm distance between panes	2.70
	double frame casement window with 2 panes, 50 mm distance between panes	2.44
	single frame wooden or plastic with double glazing	1.30
Doors	wooden door with double frame , 2 panes (50 mm gap between the panes)	2.90
	metallic frame with single glazing, no interrupted cold bridges	6.50

3.1.1.5 1981 – 1994

The period from 1981 to 1994 is dominated by the construction of blocks of flats, up to the early nineties, when it came to its end. A fundamental change in the design and construction of the exterior walls was initiated by the revision of technical standard CSN 730540, which came into force in 1979. Based on these standard requirements most of the structural systems were using 80 mm polystyrene in the exterior walls, exceptionally up to 100 mm. Most of the standardized large panel structural systems originating from the early sixties continued to be used also in this period, they were only completed with new structural systems P 1.1 and P 1.21 in the early eighties.

After 1982, the demand got stronger for practical solutions to eliminate cold bridges, especially in the joints between exterior sandwich wall elements. This was a hint on how to improve the thermal behaviour of external walls. In relation to these issues the total thickness of external walls increased. Predominating products were sandwich reinforced concrete elements with polystyrene foam inside the section. The other construction technologies, especially masonry constructions were dropping down. After 1990, the large panel constructions stepped to stagnation. After 1992 the modified standard CSN 73 0540 with new stringent technical parameters started to influence a lot the process of design and construction.

Table 18 Summary of Construction Elements for the period between 1981 – 1994

Elements	Description	U-Value [W/m²K]
Roofs	double skin roof (cold flat roof) with ventilated air gap and thermal insulation	0.46
	double skin roof (cold flat roof) with ventilated air gap and thermal insulation 120 mm glass fibre	0.35
Ceilings	timber joist ceiling with thick insulation layer between joists	0.60
Floors	concrete 190 + insulation 25mm + screed 25mm	1.10
	reinforced concrete, 6 cm insulation, cement screed	0.60
Walls	chipboard th 19mm - polystyrene th 100 mm - air gap th 30 mm not ventilated - glass th 3mm	0.76
	precast concrete sandwich wall element with 80 mm polystyrene	0.73
	precast lightweight concrete wall element th. 290 mm	0.78
Windows	single frame wooden or plastic with double glazing	1.10
Doors	wooden entrance door insulated	2.00

3.1.1.6 1994 – 2005

Another significant change in the design of opaque exterior walls was initiated by the newly modified standard CSN 73 0540 in May 1994. With regard to more demanding standard requirements new building materials with better thermal and technical properties were used. These were mainly gas aerated concrete blocks. In 1995, after five years the absolute number of completed dwellings has grown up. It counted, however, approximately only 30% of the number of dwellings completed in 1990. The prevailing construction projects were single family houses. Increasing use of flat roofs in case of rooftop extensions and use of pitched roofs for built-in apartments were observed.

Table 19 Summary of Construction Elements for the period after 1994

Elements	Description	U-Value [W/m²K]
Roofs	prefab concrete 250mm with thermal insulation 160mm	0.23
	concrete roof insulated with 140 mm of mineral fibre	0.32
Ceilings	timber joist ceiling with thick insulation layer between joists	0.60
Floors	reinforced concrete, 8 cm insulation, cement screed	0.45
Walls	honeycomb brick 175mm - 120mm insulation	0.25
	honeycomb brick	0.50
Windows	single frame wooden or plastic with double glazing	1.60
Doors	wood+polyurethan insulated entrance door	1.20

3.1.2 Building size categories

Four categories of building size where chosen based on the usual classification of the residential stock:

- Single Family House
- Terraced House
- Multi-Family House
- Apartment Block

A graphic overview of the Czech Building Typology developed within the TABULA project is shown in Figure 4.

Figure 4 Czech Building Matrix

3.2 Typology of Construction Elements

A summary of each construction element typology is show in the present section. It contains a short description of the elements which are classified by the period where they were most commonly used and their respective U-values.

3.2.1 Roofs

Table 20 Typology of Roofs

Typical Period	Description	U-Value [W/m²K]
Before 1920	roofing tiles , battens, rafters, not insulated	2.60
1921-1945	roofing tiles, battens rafters +cork or heraklit	1.64
1946-1960	roofing tiles, battens rafters +lignopor or heraklit	1.25
	roofing tiles, battens rafters +glass wool thin insulation in the cavity	0.80
	warm flat roof	0.91
1961-1980	lightweight concrete slab 150mm + screed 30mm	0.85
	warm flat roof	0.57
1981-1994	double skin roof (cold flat roof) with ventilated air gap and thermal insulation	0.46
	double skin roof (cold flat roof) with ventilated air gap and thermal insulation 120 mm glass fibre	0.35
After 1994	prefab concrete 250mm with thermal insulation 160mm	0.23
	concrete roof insulated with 140 mm of mineral fibre	0.32

3.2.2 Ceilings

Table 21 Typology of Ceilings

Typical Period	Description	U-Value [W/m²K]
Before 1920	traditional timber joist ceiling with (open-nail) flooring, dead floor - laggings - (peeled, trimmed slabs; joints filled with clay), slag (sound and heat insulation) and ceiling plaster	1.20
1921-1945	reinforced concrete, 10 mm insulation, cement screed	2.20
1946-1960	timber joist ceiling with thin insulation layer between joists	1.30
	cavity blocks ceiling below unheated attic spaces, 40 mm insulation	1.45
1961-1980	reinforced concrete, 40 mm insulation, cement screed	1.60
1981-1994	timber joist ceiling with thick insulation layer between joists	0.60

3.2.3 Floors

Table 22 Typology of Floors

Typical Period	Description	U-Value [W/m²K]
Before 1920	floor natural stone or tiles or lime clay screed with no insulation	3.23
	steel beams, brickwork vault, wooden flooring	0.80
1921-1945	reinforced concrete, 10 mm insulation, cement screed	1.50
1946-1960	concrete floor slab above technical spaces with installations, hollow core slab, 25 mm insulation	1.10
	concrete floor on the soil 25 mm insulation	1.13
1961-1980	reinforced concrete slab above basement, th. 200 mm	1.28
	flooring th. 3mm - cement screed th 40 mm - waterproofing A400 H - Fibrex th 20mm - Precast concrete floor th 190mm	1.24
1981-1994	concrete 190 + insulation 25mm + screed 25mm	1.10
	reinforced concrete, 6 cm insulation, cement screed	0.60
After 1994	reinforced concrete, 8 cm insulation, cement screed	0.45
	concrete 200 + polystyrene 60mm + screed 25mm	0.52

3.2.4 Walls

Table 23 Typology of Walls

Typical Period	Description	U-Value [W/m²K]
Before 1920	masonry solid bricks 600 mm	1.10
	masonry solid bricks 450 mm	1.36
	masonry solid bricks 300 mm	1.80
1946-1960	masonry 375 mm cavity brick CDk	1.43
1961-1980	lightweight gas aerated masonry 300 mm	1.01
	precast lightweight pumice element	1.42
	precast wall element	1.20
	chipboard th 19mm - polystyrene th 25mm - air gap th 30mm not ventilated - glass th 3mm	1.10
	RC th 100mm - Poly EPS 40mm - RC th 50mm	0.99
	RC th 150mm - Poly EPS 40mm - RC th 50mm	1.25
	RC th 100mm - Poly EPS 60mm - RC th 60mm	0.93
	slag concrete, expanded clay concrete 300 mm	1.40
1981-1994	chipboard th 19mm - polystyrene th 100 mm - air gap th 30 mm not ventilated - glass th 3mm	0.76
	precast concrete sandwich wall element with 80 mm polystyrene	0.73
	precast lightweight concrete wall element th. 290 mm	0.78
After 1994	honeycomb brick 175mm - 120mm insulation	0.25
	honeycomb brick	0.50

3.2.5 Windows

Table 24 Typology of Windows

Typical Period	Description	U-Value [W/m²K]
1921-1945	secondary glazing 2 frames, distance between frames 150-200 mm	2.40
1946-1960	double frame casement window with 2 panes, 50 mm distance between panes	2.90
1961-1980	double frame casement window with 2 panes, 50 mm distance between panes	2.70
	double frame casement window with 2 panes, 50 mm distance between panes	2.44
	single frame wooden or plastic with double glazing	1.30
1981-1994	single frame wooden or plastic with double glazing	1.10
After 1994	single frame wooden or plastic with double glazing	1.60

3.2.6 Doors

Table 25 Typology of Doors

Typical Period	Description	U-Value [W/m²K]
Before 1920	wooden door with no glazing	3.50
1946-1960	wooden door with single glazing	4.70
1961-1980	wooden door with double frame , 2 panes (50 mm gap between the panes)	2.90
	metallic frame with single glazing, no interrupted cold bridges	6.50
1981-1994	wooden entrance door insulated	2.00
After 1994	wood polyurethane insulated entrance door	1.20

3.2.7 Typology of refurbishment measures

A summary of refurbishment measures for each type of element is show in the present section. It contains a short description of the measures and their respective thermal resistance values.

Table 26 Typology of refurbishment measures by construction element

Element	Refurbishment measure: Description	Refurbishment measure: Thermal Resistance R [m²K/W]
Ceiling	5 cm mineral fibre +gypsum board	1.25
	16 cm mineral fibre +gypsum board	4.00
	add 12 cm insulation above (+ flooring if necessary)	3.43
	add 20 cm insulation above (+ flooring if necessary)	5.71
	add 30 cm insulation above (+ flooring if necessary)	8.57
Door	exchange for plastic door double glazed	0.63
	exchange for plastic door double glazed	0.77
	exchange for standard wooden door	0.38
	exchange for high t. wooden door	0.50
	exchange for high t. wooden door	0.83
Floor	6 cm mineral fibre +particle board in case of floor renovation	1.50
	sand or gravel layer, concrete, waterproofing,15 cm polystyrene + cement screed	4.00
Roof	add waterproofing layer+10 cm polystyrene	2.50
	add waterproofing layer+16 cm polystyrene	4.00
	insulate cavity between rafters 120 mm (increase the height of purlin section if necessary), leave 20 mm ventilated gap	2.51
	insulate cavity between rafters 160 mm (increase the height of purlin section if necessary), leave 20 mm ventilated gap	3.06
	insulate cavity between rafters 12 cm + add 10 cm insulation layer above the rafters	5.14
Window	exchange for plastic window double glazed	0.71
	exchange for plastic window double glazed	0.91
	exchange for plastic window double glazed	1.25
	double glazing in the exterior frame	0.91
	triple glazing in the exterior frame	1.25
Wall	add 8 cm of insulation + plaster (external insulated render system)	2.29
	add 10 cm of insulation + plaster (external insulated render system)	2.86
	add 12 cm of insulation + plaster (external insulated render system)	3.43
	add 16 cm of insulation + plaster (external insulated render system)	4.57
	partial renovation of light facade panel between windows add from exterior particle board +10 cm polystyrene or mineral fibre+rendering	2.86
	partial renovation of light facade panel between windows add from exterior particle board +13 cm polystyrene or mineral fibre+rendering	3.71
	replacement with 20 cm gas aerated concrete blocks+ 10 cm of exterior thermal insulation with polystyrene or mineral fibre+rendering	4.55

3.3 Typology of Heating System Elements

3.3.1 Heat Generators

Table 27 Typology of heat generators

Description	Period	Typical Expenditure coefficient of HG.
constant temperature non-condensing boiler	until 1986	1.43
constant temperature non-condensing boiler	from 1987 to 1994	1.39
constant temperature non-condensing boiler	from 1995	1.28
low-temperature non-condensing boiler	from 1987 to 1994	1.33
low-temperature non-condensing boiler	from 1995	1.25
condensing boiler	until 1986	1.087
condensing boiler	from 1987 to 1994	1.064
condensing boiler	from 1995	1.05
wood pellets boiler		1.33
solid fuel boiler - coal	till 1994	1.82
solid fuel boiler -coke	till 1994	1.54
solid fuel boiler automatic		1.35
district heating central substation		1.053
district heating building substation		1.02
electrical heat pump, heat source: soil, ground water or water stream, without heating rod	until 1994	0.32
electrical heat pump, heat source: soil, ground water or water stream, without heating rod	from 1995	0.29
electrical heat pump, heat source: external air, without heating rod	until 1994	0.42
electrical heat pump, heat source: external air, without heating rod	from 1995	0.35
combined heat and power engine		1.67
electrical night storage space heater		1.00

3.3.2 Heat Storage

Table 28 Typology of heat storage systems

Description	Period	Typical heat loss of HS.
buffer storage for electric heat pumps or night-storage systems	until 1994	11.0
buffer storage for electric heat pumps or night-storage systems	from 1995	9.5
buffer storage for wood boilers	until 1994	12.2
buffer storage for wood boilers	from 1995	7.9

3.3.3 Heat Distribution

Table 29 Typology of heat distribution systems

Description	Period	Typical heat loss of HD.
central distribution, distribution pipes in unheated spaces	till 1978	33
central distribution, distribution pipes in unheated spaces	1979-1994	23
central distribution, distribution pipes in unheated spaces	from 1995-2005	16
central distribution, distribution pipes in unheated spaces, more than 5 storeys	from 1995-2005	13
central distribution, distribution pipes in unheated spaces	from 2005	8.5
central distribution, completely in the thermal envelope		7

3.3.4 Auxiliary heat energy

Table 30 Typology of heat auxiliary energy systems

Description	Building type	Typical HA energy demand
central heating system, standard pump	single-family house	8
central heating system, standard pump	multi-family house	3
decentral heating system	general	0.5

3.4 Typology of Domestic Hot Water System Elements

3.4.1 DHW Generators

Table 31 Typology of DHW generators

Description	Period	Typical Expenditure coefficient of WG.
constant temperature non-condensing boiler	until 1986	1.54
constant temperature non-condensing boiler	from 1987 to 1994	1.49
constant temperature non-condensing boiler	from 1995	1.47
low temperature non-condensing boiler	from 1987 to 1994	1.43
low temperature non-condensing boiler	from 1995	1.33
condensing boiler	until 1986	1.32
condensing boiler	from 1987 to 1994	1.27
condensing boiler	from 1995	1.18
wood-pellets boiler		1.33
electrical heat pump, heat source: soil, ground water or water stream	until 1994	0.32
electrical heat pump, heat source: soil, ground water or water stream	from 1995	0.29
electrical heat pump, heat source: air	until 1994	0.42
electrical heat pump, heat source: air	from 1995	0.35
exhaust air heat pump		0.30
electric instantaneous water heater (tankless)	from 1981 to 1990	1.00
gas-fired instantaneous water heater (tankless)	until 1994	1.35
gas-fired instantaneous water heater (tankless)	from 1995	1.31
directly gas heated hot water storage		1.34
thermal solar plant		0.00
district heating central substation		1.05
district heating building substation		1.02

3.4.2 Heat Storage

Table 32 Typology of DHW storage systems

Description	Period	Typical heat loss of WS.
Directly gas heated hot water storage		18
Decentral electric hot water storage	till 1994	6
Decentral electric hot water storage	from 1995	3.9
central hot water storage, outside thermal envelope	until 1994	12
central hot water storage, outside thermal envelope	from 1995	6.5
central hot water storage, inside thermal envelope	until 1994	12
central hot water storage, inside thermal envelope	from 1995	6.5
central hot water storage, outside thermal envelope	until 1994	2.2
central hot water storage, outside thermal envelope	from 1995	1.1
central hot water storage, inside thermal envelope	until 1994	2.2
central hot water storage, inside thermal envelope	from 1995	1.1

3.4.3 DHW Distribution

Table 33 Typology of DHW distribution systems

Description	Period	Typical heat loss of WD.
central system with circulation loop	until 1978	29.6
central system with circulation loop	from 1979 to 1994	10.8
central system with circulation loop	from 1995	7.1
central system without circulation loop	from 1995	4.4
central system with circulation loop	until 1978	34.0
central system with circulation loop	from 1979 to 1994	10.6
central system with circulation loop	from 1995	7.0
decentral system	until 1994	5.1
decentral system	from 1995	1.5

3.4.4 DHW auxiliary energy

Table 34 Typology of DHW auxiliary energy systems

Description	Building type	Typical WA energy demand
central domestic hot water system, with circulation pump	SUH	1.6
central domestic hot water system, with circulation pump	MUH	1.2
decentral dhw system	General	0.0
central domestic hot water system with thermal solar system, with circulation pump	SUH	2.5
central domestic hot water system with thermal solar system, with circulation pump	MUH	1.5
central domestic hot water system, no circulation pump	General	0.4

3.5 Typology of refurbishment measures for supply systems

Table 35 Inventory of refurbishment measures

Building type	Current	Standard refurbishment	Advanced refurbishment
Single-unit housing	Heat night storage electric stove, electric instant water heater	condensing gas boiler	solar WG + condensing boiler
	Combined H + DHW gas boiler (constant temperature, poor efficiency)	condensing boiler	solar WG + condensing boiler
	Combined H + DHW gas boiler (constant temperature, low efficiency)	condensing boiler	el. heat pump with solar WG + heat recovery in ventilation
Multi-unit housing	District heating	district heating with substation in the building	district heating with substation in the building + solar WG+heat recovery in ventilation system
	Heat night storage electric stove	condensing boiler	solar WG + condensing boiler+heat recovery
	Combined H +DHW gas boiler (constant temperature, poor efficiency)	condensing boiler	solar WG + condensing boiler+heat recovery in ventilation system

Chapter 4 Energy balance

4.1 Building Typology Approach

Six reference building-types were created to represent the housing stock for the purpose of energy balance analysis. This set of buildings is categorized by size and age as follows:

- single family house until 1979 (“SFH. 1”);
- single family house from 1980 to 2001 (“SFH.2”);
- single family house from 2002 to 2010 (“SFH.3”);
- multi-family house and apartment block until 1979 (“APT.1”);
- multi-family house and apartment block from 1980 to 2001 (“APT.2”);
- multi-family house and apartment block from 2002 to 2010 (“APT.3”);

The buildings are theoretical buildings based on the analysis of available statistical data and on the knowledge of historical standard requirements for the U values of the building envelope and the usual efficiency of the heating and DHW systems.

An overview of the frequencies in each category of the Czech housing stock is shown in Table 36. An overview of the total conditioned floor areas and TABULA reference areas for each category is shown in Table 37.

Table 36 Overview of the frequencies in each category of the housing stock

	Construction period		
	Until 1979	**1980-2002**	**Since 2002**
Number of dwellings in SFH category	1 649 756	424 172	139 293
Number of dwellings in APT category	1 277 705	574 438	165 648
Total number of dwellings	2 927 461	927 500	304 941

Table 37 Overview of the floor areas in each category of the housing stock

	Construction period		
	Until 1979	**1980-2002**	**Since 2002**
Net floor area ($m^2.10^3$) in SFH	159 531	41 017	13 470
TABULA reference floor area ($m^2.10^3$)in SFH	175 484	45 119	14 817
Net floor area ($m^2.10^3$) in AP	78 042	35 087	10 118
TABULA reference floor area ($m^2.10^3$) in AP	85 846	38 596	11 130

4.2 Data analysis

The statistical population was processed and analyzed using random two step approach by following strictly given criteria such as municipal/rural, SFH/MFH/AB, type of centralized/local heating, the frequency of fuel types.

It is worth mentioning that the mean value of energy consumption per dwelling, calculated from the sample data, amounts to 78.2 GJ/dwelling. According to "Energy balances of the Czech Republic in 2000, 2001 and 2002", CzSO February 2004, the specific energy consumption of households in last years was ranging within the limits 61.3 - 68.1 GJ/dwelling. Values calculated from energy balances lay in interval 78.2 +/- 15.6 GJ/dwelling. The above-mentioned data are not quite comparable because they refer to different years (with different number of heating degree days in heating season). The values of total energy consumption for the case of electricity and solid fuels combination, are extremely high and have an impact on average values of their overvaluation. Apparent overvaluation of solid fuels consumption is probably caused by inaccurate estimation of their consumption on the basis of their supplies but most probably even by non inclusion of efficiencies regarding the equipment on individual fuels and inaccurate estimation of remaining stocks.

4.3 Energy Balance Method

The energy balance model was created on basis of the statistical data collected mainly from the National census 2001 [1] and from the Microcensus ENERGO 2004 [6]. The delivered energy and the energy demand for space heating of the considered six groups of buildings was calculated using national calculation method.

The methodology is based on the delivered energy needed under standard indoor and outdoor conditions. Energy consumption of the building is defined as amount of energy needed for the fulfilment of various demands related to the standard use of the building. The national calculation method is based on the simplified dynamic calculation. The energy demand was calculated from monthly values.

The national calculation software tool (NCT) was used for this purpose. The simplified process of calculation was divided into two steps:

1) Calculation of energy demand of the synthetic buildings
2) Calculation of the energy required by the energy systems (heating and DHW systems) needed to produce the necessary heat and domestic hot water. The energy demand was calculated for a standard use of the buildings.

The following simplified assumptions were made in order to process the calculation:

- each synthetic building consisting of one conditioned zone only
- one climatic zone
- natural ventilation rate fixed at 0,5 h^{-1}

- internal temperature in the buildings considered as constant value
- average efficiency values used for heat generators, storage and distribution and heat emission in each group
- average annual consumption of DHW 23 m^3/occupant
- no air conditioning and mechanical ventilation considered as these systems are marginal for the housing sector
- partial reduction factors were used to estimate the reduced heat demand due to partial thermal refurbishments of the buildings

4.4 Energy Balance of the Residential Building Stock

The statistical tables presented above were used to define the average gross floor areas of synthetic buildings. The mean values of areas of the windows, floors, roofs/ceilings and exterior walls were estimated according to the expert knowledge of the geometrical properties of real buildings and their frequency. The U values were taken from the Czech standards valid in the period of building construction. The refurbishments play important role only in the groups APT2 and APT3.

The total reduced energy consumption is estimated to 20%. in the whole group APT2 and 10-15% in the whole group APT3. These estimations are quite modest with special regards to the fact that relatively many refurbishment projects did not meet the expectations for multiple reasons.

Most of the buildings in the groups APT2 and APT3 are heated with centralized heating thus it was possible to estimate the efficiency ratios. The heating systems in the groups of single family houses are variable. Table 11 and Table 13 were used as a basis for the calculation of primary energy and the CO_2 emissions. The overview of used values and results is presented in Table 38.

Table 38 Overview of values used for 6 groups of buildings and the calculation results

	SFH1	SFH2	SFH3	APT1	APT2	APT3
	-1945	1946-1980	1981-2001	-1945	1946-1980	1981-2001
Area (m^2)	68,7	86,6	109,7	352,0	684,0	842,9
A_{wall} (m^2)	85,4	93,1	110,6	290,0	520,8	574,3
A_{window} (m^2)	9,80	13,30	18,29	70	152	200,7
A_{floor} (m^2)	41,7	50,56	57,93	188	171	183,1
$A_{roof/ceil}$ (m^2)	50,8	63,2	72,42	216	196,65	210,6
U_{wall} ($W/m^2.K$)	1,4	1,1	0,6	1,4	1,1	0,6
U_{window} ($W/m^2.K$)	2,35	2,35	1,7	2,35	2,35	1,7
U_{floor} ($W/m^2.K$)	0,94	0,68	0,68	0,94	0,68	0,68
$U_{roof/ceil}$ ($W/m^2.K$)	0,9	0,51	0,31	0,9	0,51	0,31
Conditioned volume (m^3)	192,36	242,48	307,22	1353,6	1983,6	2389
Delivered energy ($kWh/m^2.year$)	328	261	146,5	304	215	164
Energy demand ($kWh/m^2.year$)	262	208	131	217	154	122
Number of dwellings	593 141	629 643	389 722	370 807	1 231 234	542 288
Total m^2	36382845	48797333	37674426	20082907	70648207	33122951
CO_2 (T)	5490512	5876381	2613823	2936109	6542421	2600015
Total delivered energy (GWh)	11934	12736	5519	6105	15189	5432
TOTAL (PJ)	**204,73**					

4.5 Comparison to National Statistical Data of the Residential Building Stock

There is no national methodology available to calculate the national balance however the calculated results can be compared with the PORSENNA report [2]. The most important boundary conditions of PORSENNA study are presented in Table 39. The value E_a means energy delivered to the building (consumed energy). It is obvious that the calculated delivered energy is quite close to PORSENNA estimation.

The total calculated energy used for heating, DHW and lighting of the housing stock is 204,7 PJ.

PORSENNA estimation for the year 2007 is 174 PJ for the heating and 25 PJ for the DHW. Another source of data that can be compared with the calculated results is shown in Table 11. The table published by the Ministry of Industry and Trade in 2007 shows total energy consumption for the heating and DHW which is 214,75 PJ. The standard deviation of calculated result is ±2,5%.

The CO_2 emissions were calculated by using general emission factors according to the Czech Decree No. 425/2004. The total CO_2 emissions are 26,059,000 T. The CO_2 emissions calculated according to the Table 13 are 23,586,500 T. The standard deviation of the calculated result is ± 5%.

Table 39 PORSENNA boundary conditions of the housing stock

Construction period	Until 1979	1979-1985	1985-1992	1992-2002	Since 2002	LEH	PH
Completed dwellings	2927461	386199	324563	216746	122488	None	None
SFH	1649756	172601	138748	112823	62649	None	None
APT	1277705	213598	191605	169235	79735	None	None
E_a average (kWh/m^2/year)	280	220	195	170	120	50	15
E_a SFH (kWh/m^2/year)	300	200	180	150	130		
E_a MFH+AB (kWh/m^2/year)	260	230	200	180	110		
U_{wall}	1,45-1,37	1,39-1,19	0,89-0,79	0,5	0,38-0,30	0,15	0,10-0,15
U_{roof}	0,89-0,83	0,93-0,79	0,51-0,43	0,41-0,36	0,3-0,24	0,12	0,10-0,12
$U_{ceiling/cellar}$	0,47-0,43	0,47-0,43	0,47-0,43	0,34	0,3-0,24	0,12	0,10-0,12
U_{window}	2,9	2,9	2,9	1,8	1,7	1,20-0,80	0,80

4.6 Calculation of Energy Saving Potentials

According to the recently performed study “PANELSCAN” still over 45% of large panel buildings and approximately 90% of masonry and other buildings shall be refurbished. The energy saving potential is relatively high. It was estimated by experts that by achieving U values prescribed by the latest version of the Czech standard CSN 730540 following amount of energy can be saved:

- 20% of energy in average can be saved by applying ETICS (External thermal insulation composite systems) to the exterior walls.
- 10% of energy in average can be saved by roof insulation
- 25% of energy in average can be saved by windows replacement
- heating control systems would bring savings ranging approximately between 5 and 15%
- The losses can be reduced up to 50% by insulating properly the pipes.

The above mentioned percentage figures were considered in the calculation model and distributed over the categories of buildings. The results are shown in Table 40.
The calculated overall energy saving potential is 83,6 PJ. The calculated CO2 reduction potential is 10,6 mil tons.

The biggest energy saving potential can be obviously found in the group of the oldest single family houses. It is representing nearly one third of the total housing stock energy saving potential. However it is important to mention that this is the worst documented part of the housing stock especially as for the recent renovations and the quality of works done. Another interesting group is APT2 which consists mainly of large panel buildings with rather poor quality of insulation and high degree of cold bridges. These standardized buildings offer good opportunities for optimized and solutions that can be used repeatedly.

Table 40 Energy saving and CO_2 saving potential in the housing sector

	SFH1	SFH2	SFH3	APT1	APT2	APT3
Number of dwellings	593 141	629 643	389 722	370 807	1 231 234	542 288
Total m^2	36382845	48797333	37674426	20082907	70648207	33122951
Total delivered energy (GWh)	11934	12736	5519	6105	15189	5432
CO_2 (T)	5490512	5876381	2613823	2936109	6542421	2600015
Energy saving potential (GWh)	7757	4840	1105	3236	5316	978
CO_2 saving potential (T)	3568787	2233172	523333	1556306	2289783	468118

4.7 Perspectives and Conclusions

The selected building typology approach with above described calculation models has contributed to energy balance analysis of the Czech building stock and enabled to estimate the energy saving potential and the potential for reduction of CO_2 emissions. The calculated energy balance and energy saving potential are in quite good correlation with recently conducted study from PORSENNA. It has been proved that a definition of six groups of average synthetic buildings with realistic de-termination of decisive parameters for energy behaviour is sufficient to estimate with reasonable degree of precision the energy consumption of the Czech building stock. The perspectives are mainly seen in the application of the same approach for fast and reliable analysis of different scenarios looked at the housing stock.

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